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(54) Silicon carbide Schottky diode and method of making same.

(57) A high performance silicon carbide Schottky contact (14) comprises a platinum containing contact on α-silicon carbide (11,12), specifically 6H-α silicon carbide. At least part (14a) of the platinum-containing contact may comprise platinum silicide which may be formed by annealing to convert at least part of the platinum to platinum silicide. An ohmic contact (13) to the substrate (11) is also provided. A guard ring (16) or field plate may be provided. The Schottky contact exhibits lower forward resistance, lower reverse current and higher reverse breakdown voltage than heretofore available designs.

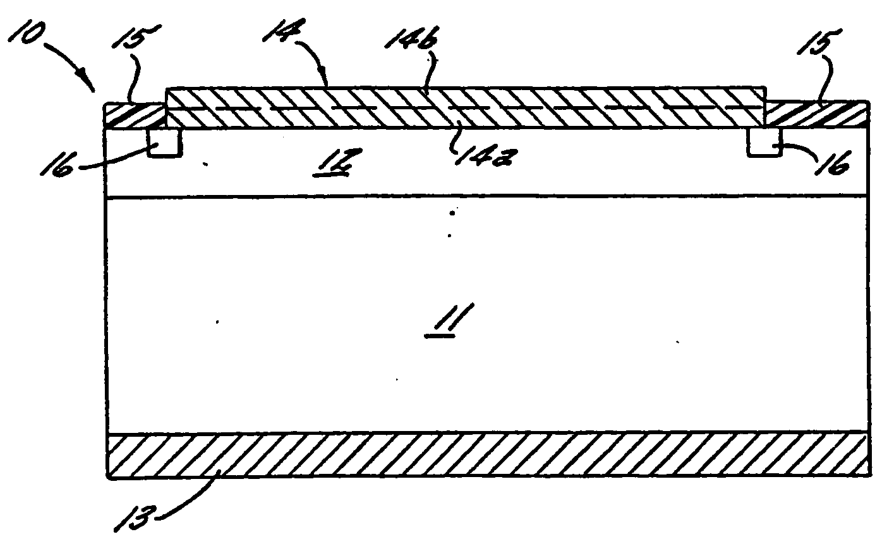


Fig. 1.

EP 0 380 340 A2

thereon, with the platinum containing Schottky contact on the n- layer. The n+ substrate provides high diode conductivity (low forward resistance) while the lightly doped n- layer provides high diode reverse breakdown voltage. An ohmic contact, for example nickel, may be provided on the n+ layer. Optionally a p-type silicon carbide guard ring may be provided in the n- layer under the periphery of the platinum containing contact, to enhance the reverse breakdown characteristics. Alternatively, a field plate may be provided over the periphery of the contact.

The Schottky diode of the present invention may be fabricated by heavily doping 6H-α silicon carbide substrate with nitrogen during crystal growth, to form the n+ layer. A thin n-layer may be epitaxially formed using chemical vapor deposition or other known techniques. Platinum may be deposited on the n- layer and then annealed at high temperature to convert at least a part of the platinum to platinum silicide. Alternatively, layers of platinum and silicon may be formed on the n- layer and annealed to convert to platinum silicide, or platinum silicide may be deposited on the n- layer

In the accompanying drawings:

Figure 1 illustrates a schematic cross section of a first embodiment of a Schottky diode according to the present invention.

Figure 2 illustrates a schematic cross section of a second embodiment of a Schottky diode according to the present invention.

Figures 3a - 3f are graphical illustrations of voltage versus current characteristics of Schottky diodes according to the present invention.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims. The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which a preferred embodiment of the invention is shown. Like numbers refer to like elements throughout. For greater clarity, the thickness of the layers has been exaggerated.

Referring now to Figure 1 a Schottky diode **10** according to the present invention is illustrated. The Schottky diode **10** includes an n+ 6H-α silicon carbide substrate **11** preferably 10-15 mils thick. Substrate **11** is heavily doped n+ to provide high conductivity (low resistance) in the forward direction. Substrate **11** is preferably doped with nitrogen at a concentration of 1×10^{18} carriers per cubic centimeter or higher. Substrate **11** may be grown using sublimination growth techniques as described in U.S. Patent No. 4,866,005 issued 12 September 1989, entitled "Sublimation of Silicon Carbide to Produce Large, Device Quality Single Crystals of Silicon Carbide".

A lightly doped n- epitaxial layer **12** of 6H-α silicon carbide, preferably 1-4 µm thick is formed on substrate **11**. This thin lightly doped layer provides a high reverse breakdown voltage for the Schottky diode and is doped with 1×10^{17} or fewer carriers per cubic centimeter. Nitrogen is the preferred dopant although phosphorous or other dopants may be used. Layer **12** may be formed by chemical vapor deposition or other known epitaxial techniques. It will be understood by those having skill in the art that in order to achieve a carrier concentration of less than 10^{17}, nitrogen dopant does not need to be be added because nitrogen is naturally incorporated in the 6H-α silicon carbide to a certain extent during chemical vapor deposition.

Schottky diode **10** also includes an ohmic contact **13** on back side of substrate **11**. The ohmic contact is preferably 4000-5000Å of nickel although other conventional contact materials such as tantalum silicide, gold, gold/ tantalum or other alloys may be employed. Ohmic contact **13** may be deposited by sputtering, evaporation or other conventional techniques, followed by a high temperature (for example 1000°C) anneal. It will be understood by those having skill in the art that because of the high temperature anneal, ohmic contact **13** is preferably formed before Schottky contact **14**.

Still referring to Figure 1 a Schottky contact **14** containing platinum is formed on n- layer **12**. As shown in Figure 1 at least part of the platinum **14a** is converted to platinum silicide by high temperature annealing, for example by annealing at 600°C for 15 minutes. The platinum silicide layer **14a** forms a stable high performance Schottky contact at temperatures up to 800°C. Platinum containing layer **14** is preferably less than 2000Å thick, and may be deposited using common techniques, for example sputtering or evaporation, and patterned by common photolithographic techniques, for example lift-off. As is well known to those having skill in the art, the platinum silicide conversion process consumes a portion of n- layer **12**. To reduce or eliminate silicon carbide consumption, platinum silicide may be directly deposited and annealed to form a unitary structure. Alternating layers of platinum and silicon may also be deposited and annealed to convert the alternating layers to platinum silicide.

A Schottky diode fabricated as described in Figure 1 has been found t provide improved diode characteristics compared to known platinum on β-silicon carbid diodes. The diodes formed according to the present invention have a higher forward resistance of less than 3.2×10^3 Ω/cm². They xhibit a reverse current which is typically below measur-

n+ layer of 6H-α silicon carbide and an n- layer of 6H-α silicon carbid on said n+ layer, with said platinum-containing contact being on said n- layer.

7. The Schottky contact of Claim 6 further comprising a p-type silicon carbide guard ring within said n- layer, lying under the periphery of said platinum containing contact.

8. The Schottky contact of Claim 6 further comprising a field plate at the periphery of said platinum-containing contact.

9. The Schottky contact of Claim 6, 7 or 8 further comprising an ohmic contact on an exposed side of said n+ layer, to thereby form a Schottky diode.

10. A Schottky diode comprising:
an n+ 6H-α silicon carbide substrate;
an ohmic contact on one side of said substrate;
an n- 6H-α silicon carbide epitaxial layer on the opposite side of said substrate; and
a platinum silicide Schottky contact on said n-layer.

11. The Schottky diode of Claim 10 wherein said n+ layer is doped with nitrogen at a concentration greater than 10^{18} carriers per cubic centimeter.

12. The Schottky diode of Claim 10 or 11 wherein said n- layer is doped with nitrogen at a concentration less than 10^{17} carriers per cubic centimeter.

13. The Schottky diode of Claim 10, 11 or 12 wherein said platinum silicide Schottky contact is less than 2000Å thick.

14 . The Schottky diode of Claim 10, 11, 12 or 13 wherein said ohmic contact comprises nickel.

15 . A method of forming a Schottky contact comprising the steps of:
providing a 6H-α silicon carbide substrate; and
forming a platinum containing contact on said 6H-α silicon carbide substrate.

16 . The method of Claim 15 wherein said forming step comprises the steps of:
forming a platinum contact on said 6H-α silicon carbide substrate; and
converting at least part of said platinum contact to platinum silicide.

17. The method of Claim 16 wherein said converting step comprises the step of annealing said platinum contact.

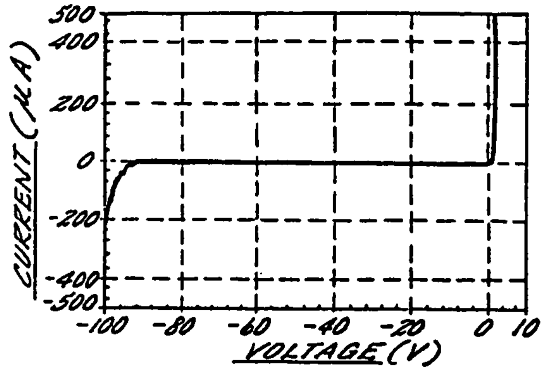
18. The method of Claim 17 wherein said annealing step comprises the step of heating said platinum contact at a temperature of at least 600°C for at least 15 minutes.

19. Th m th d of Claim 16 wherein said converting step comprises the step of converting all of said platinum contact to platinum silicide.

20. The method of Claim 15 wherein said forming step comprises the steps of:
forming a platinum silicide contact on said 6H-α silicon carbide layer.

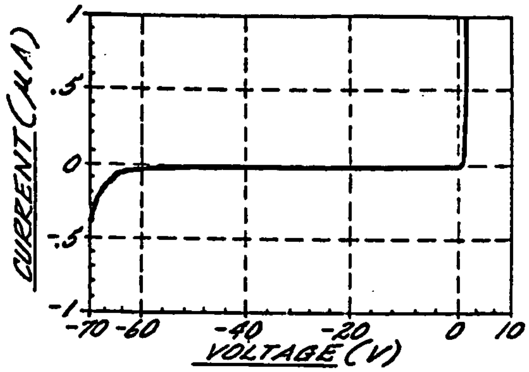
21. The method of Claim 15 wherein said forming step comprises the steps of:
forming alternating layers of platinum and silicon on said 6H-α silicon carbide layer; and
converting said alternating layers of platinum and silicon to silicon carbide.

22. The method of Claim 15 wherein said providing step comprises the steps of:
providing an n+ 6H-α silicon carbide substrate;
epitaxially forming an n- layer of 6H-α silicon carbide on said substrate; and
wherein said forming step comprises the step of forming a platinum-containing contact on said n-layer.



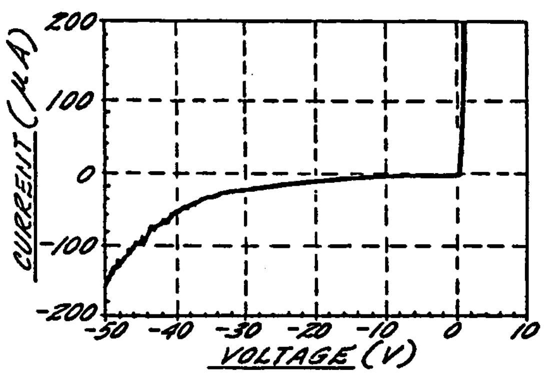
ROOM TEMPERATURE - NO ANNEAL

Fig. 3a.



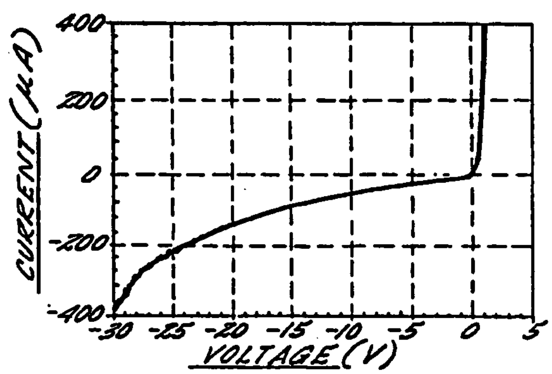
ROOM TEMPERATURE - AFTER 15 MIN. ANNEAL AT 600°C

Fig. 3b.



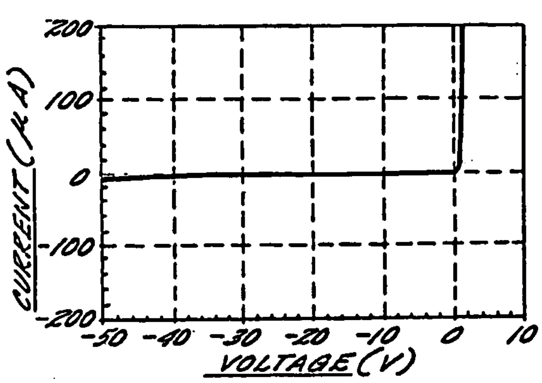
TEMPERATURE 300°C - AFTER 30 MIN. ANNEAL AT 400°C

Fig. 3c.



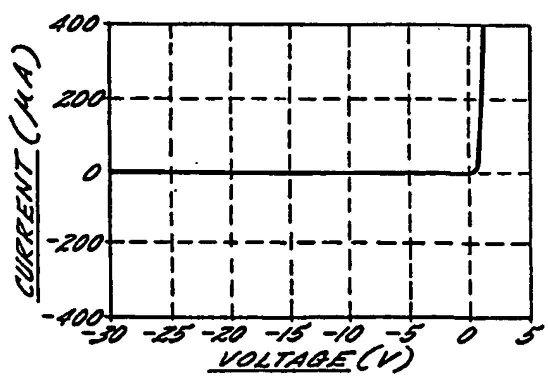
TEMPERATURE 400°C - AFTER 30 MIN. ANNEAL AT 400°C

Fig. 3d.



TEMPERATURE 300°C - AFTER 15 MIN. ANNEAL AT 600°C

Fig. 3e.



TEMPERATURE 400°C - AFTER 15 MIN. ANNEAL AT 600°C

Fig. 3f.

European
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EUROPEAN SEARCH REPORT

Application Number

EP 90 30 0796

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	APPLIED PHYSICS LETTERS. vol. 46, no. 8, April 1985, NEW YORK US pages 766 - 768; S.Yoshida et al.: "Schottky Barrier Diodes on 3C-SiC" * abstract *	1	H 01 L 29/91
A	SOLID STATE ELECTRONICS. vol. 20, no. 6, June 1977, OXFORD GB pages 499 - 506; A.Rusu et al.: "THE METAL-OVERLAP LATERALLY-DIFFUSED (MOLD) SCHOTTKY DIODE." * figure 1 *	7-9	
P,A	JOURNAL OF APPLIED PHYSICS. vol. 65, no. 9, May 1989, NEW YORK US pages 3526 - 3530; N.A.Papanicolaou et al.: "Pt and PtSix Contacts on n-type beta-SiC" * abstract *	1-5	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H 01 L

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	11 December 90	NILES N.P.E.

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
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A: technological background
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